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Texture of Emulsified Cooked Meat Products by Three Different Methods of Measurement

JAY B. FOX JR., RONALD K. JENKINS, and STANLEY A. ACKERMAN

ABSTRACT

A comparison was made of Warner-Bratzler (W-B) shear with penetration and compression tests of the texture of frankfurters undergoing textural deterioration during storage in vinegar pickle. The various measurements were linearly covariant but the intercepts were finite, indicating the different tests were not measuring the same properties in the same proportions. Covariant plots of W-B shear of whole frankfurters and penetration of the interior gel showed that the skin did not deteriorate to the extent of the interior emulsion did. Covariant plots of work and maximum force values for all three techniques showed that the maximum stress forces decreased more rapidly than did the average work function during storage in pickle.

INTRODUCTION

DURING THE COURSE of studying the stability of emulsified meat products in vinegar pickle (Fox et al., 1983), we had occasion to study simultaneously the rheological properties of the gel emulsions. A survey of the literature for appropriate techniques, disclosed several commonly used techniques, one of which is the Warner-Bratzler (W-B) shear (Bratzler, 1932; Carpenter et al., 1966; Lauck, 1975; Hwang and Carpenter, 1975; Voisey et al., 1975; Whiting et al., 1981). This test measures the force required to pass a V-notched blade completely through the sample. A variation of this type of measurement is the Kramer shear technique, in which one or more flat-edged blades are forced through the material (deMan et al., 1976). Another technique, hereinafter called the "penetration" test, measures the force required to push a flat-ended ¼" (0.635 cm) cylindrical rod through the gel (Huang and Robertson, 1977; Whiting et al., 1981). A third commonly used technique measures elasticity and firmness by compressing a sample a given amount, releasing the pressure at the same rate, and measuring the energy used and released during the process (Townsend et al., 1971; Voisey et al., 1975). Voisey et al. (1975) found that of all the factors studied, rupture showed the best correlation ($r = 0.89$) with the sensory attributes of chewiness and firmness. Huang and Robertson (1977) and Quinn et al. (1979) found an equally high correlation between maximum force during penetration and tenderness. In contrast, Voisey et al. (1975) found no correlation between W-B shear and chewiness or firmness, albeit W-B shear has been a widely used technique for measuring frankfurter texture. These three techniques have not been directly compared with each other.

Some previous studies have correlated texture measurements with various ingredients, formulations, and processing conditions used in making frankfurters (Baker et al., 1968; 1969; 1970a; 1970b; 1972a; 1972b; 1972c; Carpenter et al., 1966; Quinn et al., 1979); some studies used frankfurters from various processors (Voisey et al., 1975; Quinn et al., 1979). Differences noted were due to factors not fully defined since no two sets of frankfurters were the same. The objective of this study was to determine the technique most relevant to the determination of changes in textural properties of frankfurters stored in vinegar pickle (Fox et al., 1983) and simultaneously compare the various techniques with each other to more clearly define the textural parameters being measured.

Authors Fox, Jenkins, and Ackerman are with the USDA-ARS, Eastern Regional Research Center, 600 E. Mermaid Lane, Philadelphia, PA 19118.

MATERIALS & METHODS

Emulsion

The frankfurters were made from a formulation consisting, in part, of lean beef and pork and pork fat, to yield a finished product containing 11% protein and 30% fat. The weights of raw ingredients used in a 5-kg batch of emulsion were calculated by a program written for a TI-59 programmable calculator, using the proximate composition of the protein, fat, and water of the beef, pork, and fat as input. Beef protein content was set at 63% of total protein. The following additives were used: 1.2% spice mix, 125 ppm $NaNO_2$, 425 ppm sodium ascorbate, 1.6% sugar, and 2.0% NaCl. Water, as ice, was added to 10% excess to allow for water loss during processing. The ingredients were chopped in a Koch-Alpina KA 110 cutter at 2500 rpm starting with the beef and lean pork. The spice, nitrite, ascorbate, sugar, and salt were premixed and added at 0.5 min; 2/3 of the ice at 1.0 min, the fat, and the remainder of the ice at 3.5 min (2.0°C). The emulsion was chopped until it attained a temperature of 16°C (9–10 min). The emulsion was stuffed into Union Carbide C-25 (23 mm diameter) casings, linked, and processed with hickory smoke in a smokehouse to an internal temperature of 68.3°C.

Pickling

Twenty frankfurters from each batch were placed in 2-qt Mason jars and covered with 500 ml of 5% acid vinegar. As samples were withdrawn, the vinegar was replenished to keep the frankfurters covered. Jars of the pickled frankfurters were then stored at 3°C and 37°C.

Warner-Bratzler (W-B) and Kramer shear

A Chatillon Model SD-50 W-B shear apparatus was used to obtain cross-sectional shear values for the first set of frankfurters. In order to obtain further and more precise information in subsequent studies, a W-B shear plate with a V-notch was made that could be clamped in the vise jaws of an Instron 1122 instrument, using the two shear bars of the Chatillon apparatus. For shear measurements, a frankfurter section with or without the skin, rested on the two shear bars. The plate was then forced down through the section until the tip of the V-notch was just below the plane of the top of the bars. The shear bars were supported on the table of the load cell, which measured the force required to shear the frankfurters. The cross-head speed was set at 5 cm/min, the speed recommended by Huang and Robertson, (1977) and the cycle set for fast return of the cross-head. Both the maximum force and total work required to move the blade through the sample were recorded. For the Kramer-type shear measurements, a square notch was cut in the shear blade opposite the W-B notch.

Penetration

A ¼" (0.635 cm) diameter rod was used for penetration measurements (P) (Huang and Robertson, 1977). To provide a good gripping surface for the cross-head jaws, the rod was welded to the edge of a ¼" plate. After clamping the plate in the jaws, the cross-head was raised until the rod's bottom surface was 3.0 cm from the load cell plate. The downward travel was set for 2.8 cm, at a rate of 5.0 cm/min, with automatic return. Sections 2.5-cm long were cut at random from the frankfurters and placed vertically on the load cell so that the rod penetrated the core of the frankfurter. Both the maximum force and total energy required to penetrate the gel were recorded.

Compression tests

The multiple compression technique (Townsend et al., 1971) was modified to use the capabilities of the Instron 1122. The Instron was equipped with a continuously reversing drive that enables repeated compression of the samples. A "T" bar was inverted in the cross-head vise so that the top of the "T" formed a compression plate, 2.54 cm square, parallel to the load cell plate. The cross-head was raised to produce a 1-cm clearance between the two plates, and the downward travel set at 0.5 cm, with a drive speed of 5.0 cm/min. The instrument was set in the continuous cycle mode. One centimeter samples were cut transversely through the frankfurters, from which discs of 1.6-cm diameter were cut with a No. 11 cork borer. A disc was then placed between the two plates and the compression/release cycle repeated five times. In addition to recording maximum compression forces (CF), two measures of elasticity were taken: (1) the ratio of the energy released during decompression to the energy required to compress the sample (decompression/compression, D/C) (Townsend et al., 1971), and (2) the ratio of the maximum force required to compress the sample during the fifth cycle to the force required for the initial compression (multiple compression, MC).

The maximum force exerted during testing was recorded unless it occurred at the very end of the downward excursion. The work (energy) values used in the decompression/compression measurement were determined by integrating the area under the force-distance curve with the Instron A-1022 integrator. Two D/C measurements were taken, one of the first compression cycle and one of the total integrated areas over the five cycles. From these values we could calculate the D/C values for the four succeeding compression cycles. For all of the foregoing measurements, three frankfurters were chosen at random from each batch. Three samples were cut from each frankfurter for measurement so that each data point is the average of nine replicate measurements.

Covariance and statistical analysis

In order to compare the various techniques with each other the data for two different measurements were plotted covariantly, that is, one as a function of the other. The covariant curves so obtained were statistically analyzed for significance of slope and intercept by standard techniques (Steel and Torrie, 1960). Measurements were made of six different sets consisting of four to six individual batches each. In order to evaluate the different techniques in terms of sensitivity and utility, the coefficients of variation for sample replicates (n = 9) were compared with the ranges of both the initial samples, representing the variability in batch preparation, and the stored samples representing the change due to texture deterioration. For ease of visualization the comparison is shown as a ratio, R/cv. .

Terminology. D/C – ratio of energy released during decompression to energy expended during compression; CF – maximum compression force; MC – multiple compression ratio of fifth to first maximum compression force peaks; P – maximum force exerted during penetration; W-B – maximum force exerted during W-B shear; K – maximum force exerted during Kramer-type shear.

RESULTS

Test patterns

Fig. 1 shows typical patterns obtained with the three methods of measurement. The W-B shear pattern shows the typical high peak when the skin was ruptured, followed by a lower series of peaks due to compression and shear of the core. The second set of patterns were typical of P measurements and of W-B shear measurements of frankfurters with the skin removed. The third set, for the compression test, show the sharp well defined peak typical of a fresh frankfurter gel which did not rupture. The ragged lower peak pattern occurred when the aged gels ruptured during compression. The upper W-B and penetration curves for fresh frankfurters are very similar to those reported earlier (Huang and Robertson, 1978; Voisey et al., 1975) and are compared with the lower curves which show the effects of aging in pickle.

Measurement-covariance of W-B and P

Warner-Bratzler shear was applied radially to the frankfurters and measured both the shear of the skin and the shear of the interior gel, whereas, the pin penetration was applied axially and measured compression and shear of the gel only. The covariant plot of the W-B and P maximum force values of set 2 is shown in Fig. 2a. The data represent the change in both measurements with time in vinegar at 3°C and 37°C. The intercept of the curve of Fig. 2a was significantly ($p < 0.001$) different from zero, that is W-B shear measured a factor not measured by the P method. The deviation appeared to be due to the skin since the latter retained an appreciable texture after the gel had turned soft. This was only an assumption, since the deviation is a relative relationship between W-B shear and penetration. To test the assumption, 1.5-cm cores were taken from frankfurters and tested by the W-B and P techniques (Fig. 2b). Again the curve was a straight line, but the W-B intercept was now negative. The downward shift confirmed the assumption that the skin did not deteriorate to the same extent as the gel, but the two techniques did not measure the same gel properties equally. Since the surface area to

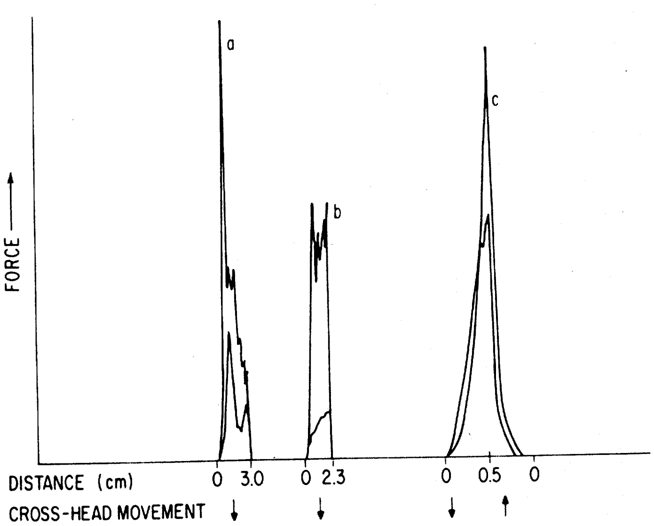

Fig. 1—Force-distance patterns for the three textural measurement methods: (a) Warner Bratzler with skin; (b) penetration or Warner-Bratzler without skin; (c) compression.

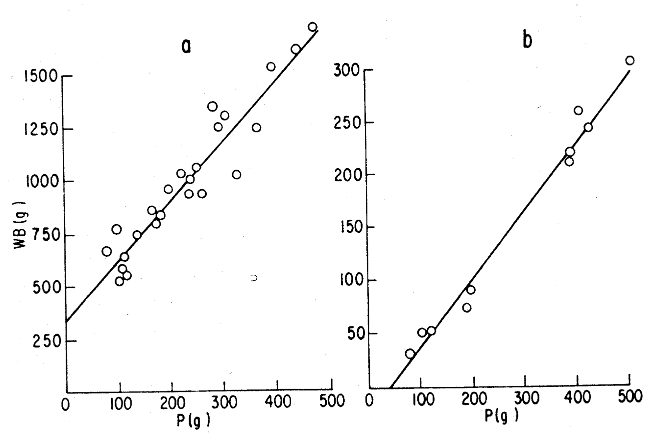

Fig. 2—Covariant plots of the maximum force values observed for Warner-Bratzler shear (WB) and penetration (P) measurements: (a) with skin; (b) without skin.

shearing edge ratio was greater for the penetration rod than it was for the W-B shear plate, the former measured relatively more compression force than the latter. Furthermore, the W-B shear blade moved laterally past the surface of the frankfurter gel, producing a slicing component which also led to a lowering of the required rupturing forces. The presence of an increased compression factor in the P values and/or a decreased rupture factor in the W-B values are the most likely reasons for the residual factor in the ordinate values of Fig. 2b.

Warner-Bratzler and Kramer shear

The maximum force data for W-B and Kramer shear measurements of frankfurter cores during storage in pickle were calculated as covariant values. The regression curve for the data is:

$$\text{W.-B.} = 0.818\,\text{K} + 6.7, \quad r = 0.97$$

In this regression the intercept was not significantly different from zero, but the W-B shear blade required only 82% of the force required by the Kramer shear blade. Pool and Klose (1969) observed that one of the forces in shearing was sample distortion before shear commenced, which in W-B shear is forcing the round shape into a triangular form and in Kramer shear is flattening of the sample. Furthermore as noted, W-B shear had a slicing component not present in Kramer shear. Nevertheless, the shear patterns of the two blades were the same (Fig. 1). The slopes of the initial portions of the curves, which are functions of the stress-strain relationship (Voisey et al., 1975), were not significantly different ($p = 0.8$) from each other, which might have been expected if the distortion factors were different. The only difference between the measurements on any given core was the lower rupture points and total work of the W-B measurements. Thus the lesser force required by W-B shear was due to the micro-rupturing of the gel structure by the slicing action of the V-notch.

Elasticity

The covariant plot for the multiple compression (MC) and decompression/compression (D/C(1)) ratios for the second set of frankfurters is shown in Fig. 3. As observed with the shear and penetration data of Fig. 2, most of the compression data show a straight line relationship, but the extrapolated curve for the upper part of the data does not pass through the origin. Furthermore, after 12–19 days of storage, the MC values stabilized at a ratio of 0.5–0.6, resulting in a leveling off of the curve. Two events that bear on these phenomena were noted: (1) a breakdown of the gel during the first compression cycle, also noted by Voisey et al. (1975), and (2) a recovery of elasticity. While the fresh samples showed no evidence of physical damage, the yield points of the aged gels were exceeded during the first compression cycle, resulting in both a plastic flow and a rupture of the sample. Plastic flow was exhibited by the gels at the ends of the curves, that is the freshest and the oldest, whereas rupture predominated in the intermediate samples. This rupture and/or flow resulted in a lack of recovery of the original sample thickness during decompression. When the yield points of the gels were exceeded, part of the work performed during compression was used in the rupture and flow processes, hence the recovery of energy during decompression was lessened. After the initial compression cycle, subsequent cycles did not exceed the rupture point and a larger proportion of the energy was recovered (Table 1). In fact, while the D/C(1) values continued to decrease with storage in vinegar pickle, to 10% of their initial values, the D/C(4) values stabilized after 3 days at about 0.4–0.6.

Table 1—Comparison of energy functions from compression studies of frankfurter emulsions stored in vinegar for 3 days at 3 and 37°C

(1) Sample	(2) D/C (1)	(3) D/C (4)
Cold-control	0.341	0.548
Xanthan	0.365	0.592
Locust bean	0.352	0.536
X/LB[a]	0.346	0.551
Hot-control	0.309	0.505
Xanthan	0.313	0.510
Locust bean	0.292	0.496
X/LB	0.277	0.469

[a] Mixture of xanthan and locust bean gums, 0.25% each

Compressive force

The maximum force exerted during compression (CF) was compared with both the D/C(1) and the P (force) values. The covariant regressions in both cases were linear.

$$(1)\ \text{D/C}(1) = 0.305\,\text{CF} + 0.095 \quad S_{y \cdot x} = 0.036,\quad r = 0.913 \quad t_{intercept} = 4.82$$

$$(2)\ \text{P} = 0.626\,\text{CF} - 0.003 \quad S_{y \cdot x} = 0.059,\quad r = 0.942 \quad t_{intercept} = 0.088$$

The slopes were significant at the $p < 0.001$ level and the intercept of the D/C(1) plot was significantly different from zero ($p < 0.05$), while the intercept of the P plot was not. There was not a priori reason to expect elasticity to be linear with compressibility, but that it was implies a relationship between the two. The P/CF plot was unusual in that the CF data came from samples that either ruptured randomly, flowed or did neither, whereas the P data were for a technique where compression, rupture and flow were contributing factors to all measurements. Since the regression curve measured the same properties in the same proportions, penetration and maximum compressive force are equivalent techniques.

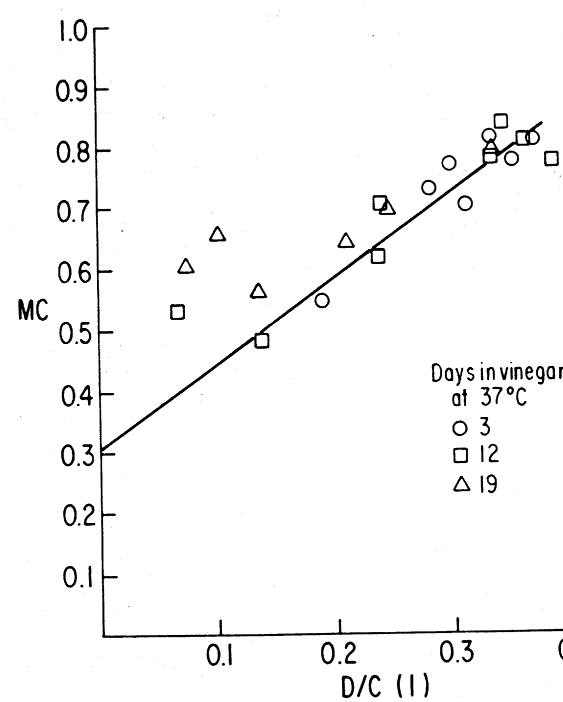

Fig. 3—Covariant plot for multiple compression (MC) and decompression/compression (D/C) values from the compression tests.

Sensitivity

The ratio range/coefficient of variation (R/cv), is the measure of the sensitivity of a given technique; the larger the ratio, the greater the sensitivity (Table 2). Batch sensitivity was greatest for W-B and maximum compression forces and decompression/compression, while the deterioration sensitivity was greatest for penetration and maximum compressive force and decompression/compression. The reduced sensitivity of the W-B shear measurements was due to the lessened deterioration of the skin during storage in pickle as compared to the gel deterioration.

Force versus work

The work values for the C, W-B, and P measurements are plotted in Figure 4 as a function of the corresponding maximum force values. The work function used for the compression plot was the area under the curve during the compression phase of the first cycle. If there were no force there could be no work function and, in practice, the curves must pass through the origin. While the P and MC plots showed a downward curve at the lower values, the bulk of the data showed a residual work function, represented by the abscissa value at the intercept of the extrapolated regression line when F = 0. The difference from zero is significant at the $p < 0.001$ level. We assumed that the upper portion of the observed regression line contained an artifact either of measurement or textural characteristic. We rejected measurement since tests of the Instron at varying speeds with varying resistances showed no significant differences in either maximum force (pen response) or work function (integrator response) with cross-head speeds up to 50 mm/min. At 50 mm/min, the pen and integrator response were both reduced by about 2%, which did not account for the observed displacement.

The curve may be made to pass through the origin in one of three ways: (1) statistical forcing, (2) lateral displacement to the right, or (3) counter-clockwise rotation. Statistical forcing was not valid for these data nor was lateral displacement since the latter would have required a 500% error in the lower measurements. Rotation of the curve may be accomplished by subtracting successively larger values from successively larger abscissa values, assuming that the maximum force values became increasingly too large the higher the value. To explain, referring to Fig. 4d, the areas under the two figures represent the work function ($w = \overline{F}xd$) where $\overline{F}$ is the average force represented by the dotted line. The difference between the force maxima and

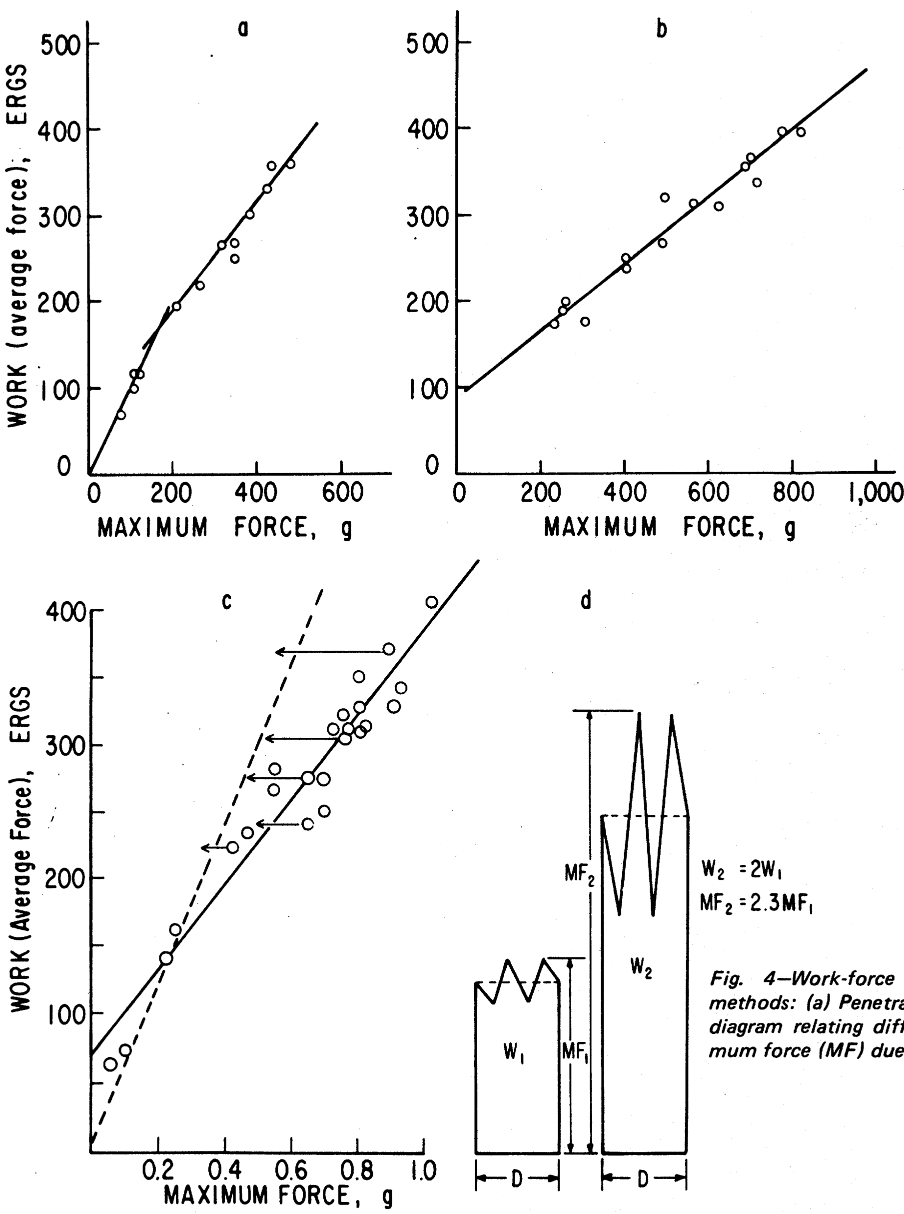

Fig. 4—Work-force plots for the three textural measurements methods: (a) Penetration; (b) Warner-Bratzler; (c) compression; (d) diagram relating differences between average work (W) and maximum force (MF) due to different coefficients of variation.

Table 2—Evaluation of various methods for measuring the textural characteristics of frankfurter emulsions

Technique	Fresh cv (%)	Fresh R/cv	Fresh Range[a]	Aged cv (%)	Aged R/cv	Aged Range[a]
Varner-Bratzler						
Maximum force (W-B)	7.5	3.87	29	25.8	2.70	70
Work	9.1	2.64	24	18.5	3.00	57
Penetration						
Maximum force (P)	8.6	1.86	16	17.7	4.97	88
Work	7.5	2.13	16	19.8	4.34	86
Compression						
Maximum force (CF)	12.8	3.51	45	16.6	5.60	93
Multiple compression (MC)	2.6	2.59	7.0	8.4	2.50	21
Decompression/compression (D/C)	5.2	3.85	20	15.3	5.23	80

[a] Range defined as $\frac{\text{maximum} - \text{minimum}}{\text{maximum}} \times 100\%$

minima was greater for the second figure than for the first ($cv_2 = 3\ cv_1$), and the second maximum force value was 2.3 times the first even though the second work function is only twice the first. Upon examination of the shear and penetration patterns (Fig. 1) it is observed that the peak maxima and minima of the fresh and cold vinegar samples show a greater deviation from the average than do the peaks of the aged, warm vinegar samples, and the larger the maximum compressive force value, the larger the deviation from the average. Subtracting progressively larger increments from increasingly larger abscissa values rotates the curve counter-clockwise to pass through the origin, as shown by the dashed line in Fig. 4c.

DISCUSSION

WE BELIEVE that this change in deviation in the force patterns has a physical significance. For example, in the penetration technique, the force applied during the downware movement of the cross-head rose to a maximum, at which point shear and/or rupture took place. The force fell off, to rise again to a new maximum when the process was repeated. It is hypothesized that these successive maxima represent the shearing or rupturing of planes or sheets in the gel. These planes represent a more resistant structure in the gel network. After each successive rupture, the applied force did not drop to zero, but instead there was a residual resistance to the rod movement, attributable to a less resistant structure. The more resistant structure would be part of the denatured protein film which acted as the emulsifying agent in the frankfurter gel emulsion. During acid deterioration, the protein network was progressively degraded, the force required to shear or rupture the membranes decreased, and the deviation from the average force decreased. The less-resistant, acid-stable structure may be either just a suspension of oil in water, an emulsion formed from an acid-resistant protein, other endogenous emulsifying agents, phospholipids, nucleic acids, etc.

Evaluation of the techniques

One of the principal objectives of this study was to establish the most useful and relevant measurement technique for our purposes. For the study of aging, the penetration and the compression measurements, decompression/compression and multiple compression, had satisfactorily high property change to standard deviation ratios. As noted previously, compression and penetration measurements correlate well with sensory firmness and chewiness, whereas W-B shear and elasticity did not (Voisey et al., 1975; Quinn et al., 1979). Over a much wider range of values and under quite different conditions, our results are consistent with their findings. The linearity and zero intercept of the compression/penetration graph indicate a relationship between these two techniques, while the deviation of the W-B shear or MC (elasticity dependent) regressions with penetration or compression clearly place W-B shear and MC in a different category. The penetration/compression relationship is unusual in that the two methods did not uniformly measure the same rheological properties. Pin penetration always involved both rupture and compression, but the compression tests involved samples that variously did or did not rupture, or flowed smoothly. Barring happenstance, this implies that firmness and rupture are either interdependent properties of the gels, or simply different expressions of but one basic property. If so, the different methods used may not be as specific to fundamental gel characteristics as heretofore assumed.

Voisey and Larmond (1974) quantitated the increase in W-B shear force with increasing angle of the notch, and observed a leveling off of the shear at an angle of 60°, the angle of the W-B shear plate. In contrast, in this study we found an 82% difference between the W-B and the flat blade (90°) shear forces. They interpret their results in terms of greater force per unit distance of blade contact, but in our samples blade contact distance was longer in W-B than in Kramer-type shear, which would have required more, not less, total force to increase the force/distance value. The test patterns of Voisey and Larmond (1974) showed one single rupture peak, while our samples showed almost equal height peaks during the entire shearing process. A close examination of the action of the action of the W-B blade as it moved through the frankfurter showed lateral movement of the gel with respect to the blade, thus introducing the slicing component into W-B shear. That W-B shear did not correlate with sensory results (Voisey et al., 1975) seems somewhat unusual, for skin texture is important to the overall sensory characteristics of frankfurters (Huang and Robertson, 1977). As our results show, skin texture is only partly related to interior gel texture and would be expected to be a separate but detectable factor in sensory evaluation. A possible explanation for both the lack of correlation and the blade angle results is that Voisey et al. (1975) used frankfurters with skins so soft that variations in skin shear were relatively negligible with respect to gel firmness and shear. Our frankfurters were processed in a smokehouse with wood smoke and had a very firm skin. As Voisey and Larmond concluded, "the test (W-B) requires more sophisticated interpretation than is normally used."

We have concluded that for our interests the penetration technique was the most useful. However, differences between the techniques provided insights into the process, and all measurements would be useful to an in-depth properties study of emulsion-derived meat products (bologna, frankfurters, etc.). In some previous studies (Carpenter et al., 1966; Rongey and Bratzler, 1966) the initial variations in rheological properties of meat emulsions were not significant, in others they were (Voisey et al., 1975; Quinn et al., 1979). Because the variations in the initial samples were slight, a statistical analysis would not necessarily detect systematic variations between them, but the present study, which measured a broader range of values, indicates that in fact the variations were significant, both in the fresh and aged samples. Since the broad range of values were produced in samples stored in warm pickle, the use of acid deterioration is a useful technique for evaluating gel properties and establishing relationships between different methods of measurements.

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